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Torsional Analysis Challenges of a Centrifugal Pump Train

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Presenter bios

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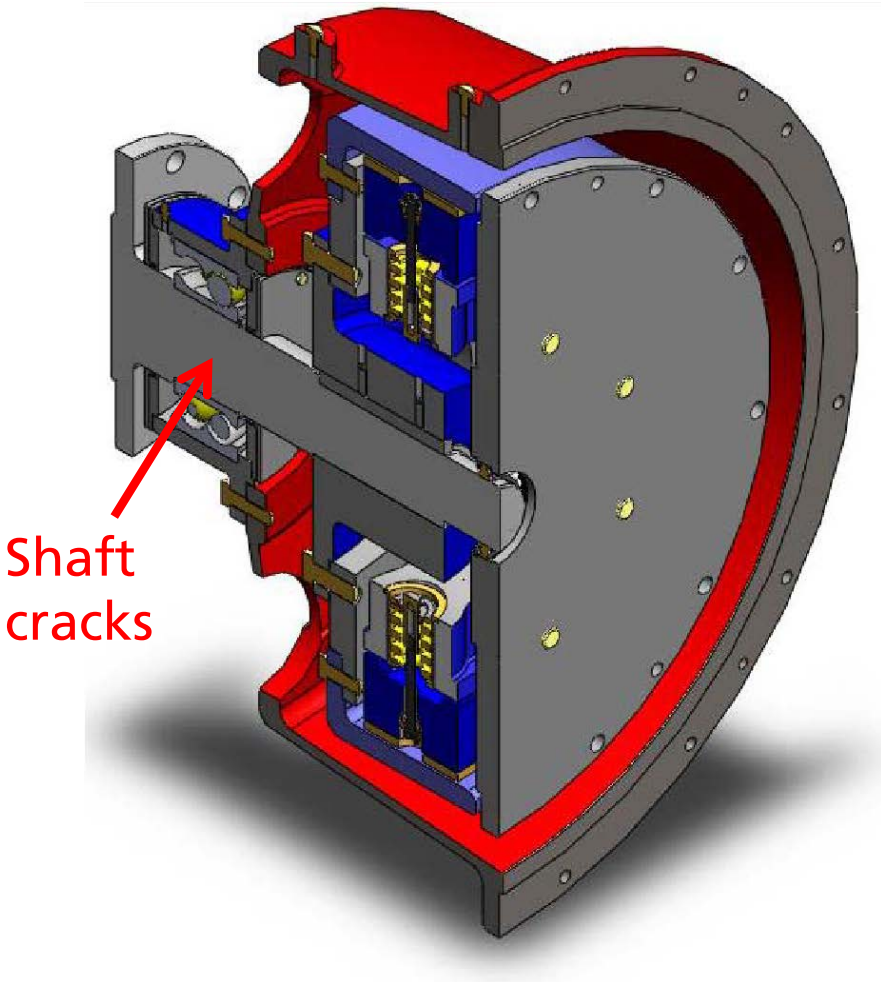
Background – North Rankin B firewater pumps

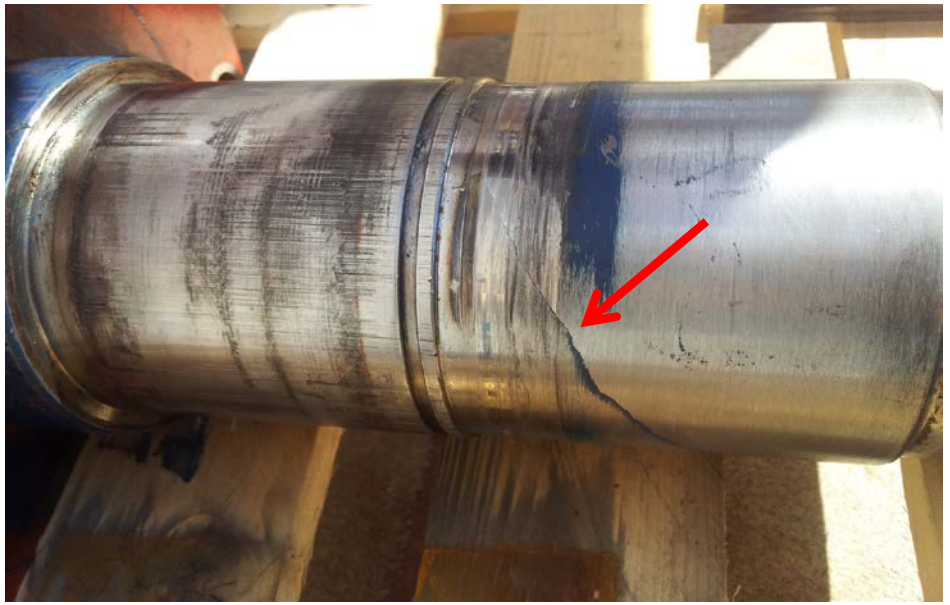
- North Rankin B gas processing platform
- Located 135 km off the north-west coast of Western Australia
- Operated by Woodside Energy Ltd.
- During the early engineering phase a decision was made to change the pump set from a 3 x 60% to a 2 x 100% to save on space and weight on the platform.
  - For unknown reasons a diesel engine with an undersized starter system was purchased for the pump string.
  - When the equipment inertias were calculated it was determined that the diesel engine starter might not be able to start the whole string.
  - Therefore it was decided to use a centrifugal clutch so the engine could be started without being connected to the pump.
- Torsional analysis during procurement of firewater pump package did not identify the shaft as being susceptible to failure.

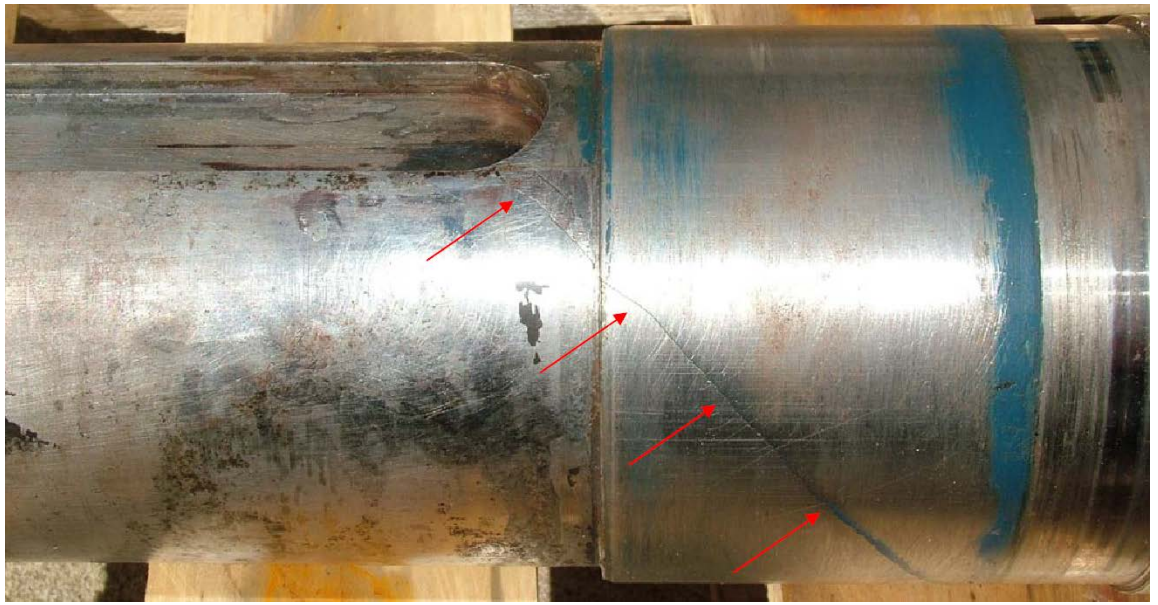
Problem statement

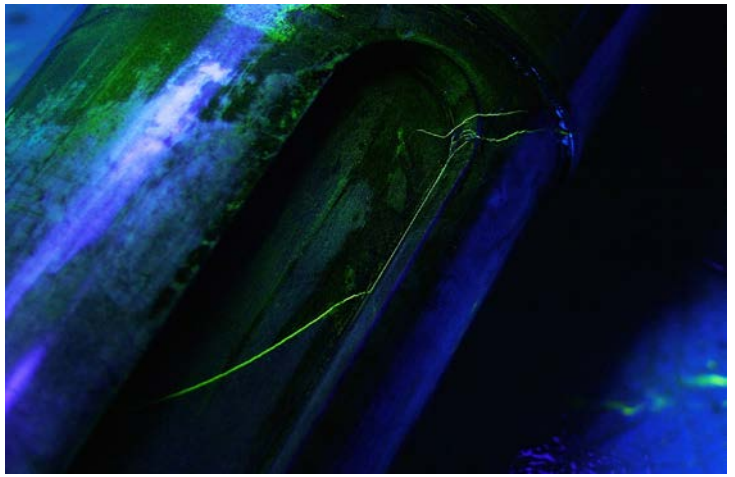
- Failures on the centrifugal clutch shaft of two firewater pumps (A & B) during commissioning in September 2012. Cracks discovered after (10 & 40) hours of running time.
- Shaft crack angle indicated failure was due to excessive torsional load applied to the clutch shaft.
- The goal became to update the torsional model from measurements so that it could reproduce the measured torsional response. This updated model was then going to be used for selecting an alternative driveline between the diesel engine and the gearbox.

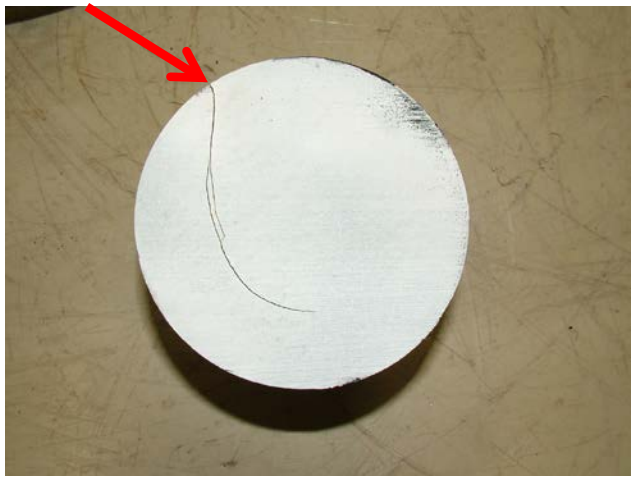


Clutch shaft failure photos









North Rankin B firewater pump drivetrain configuration

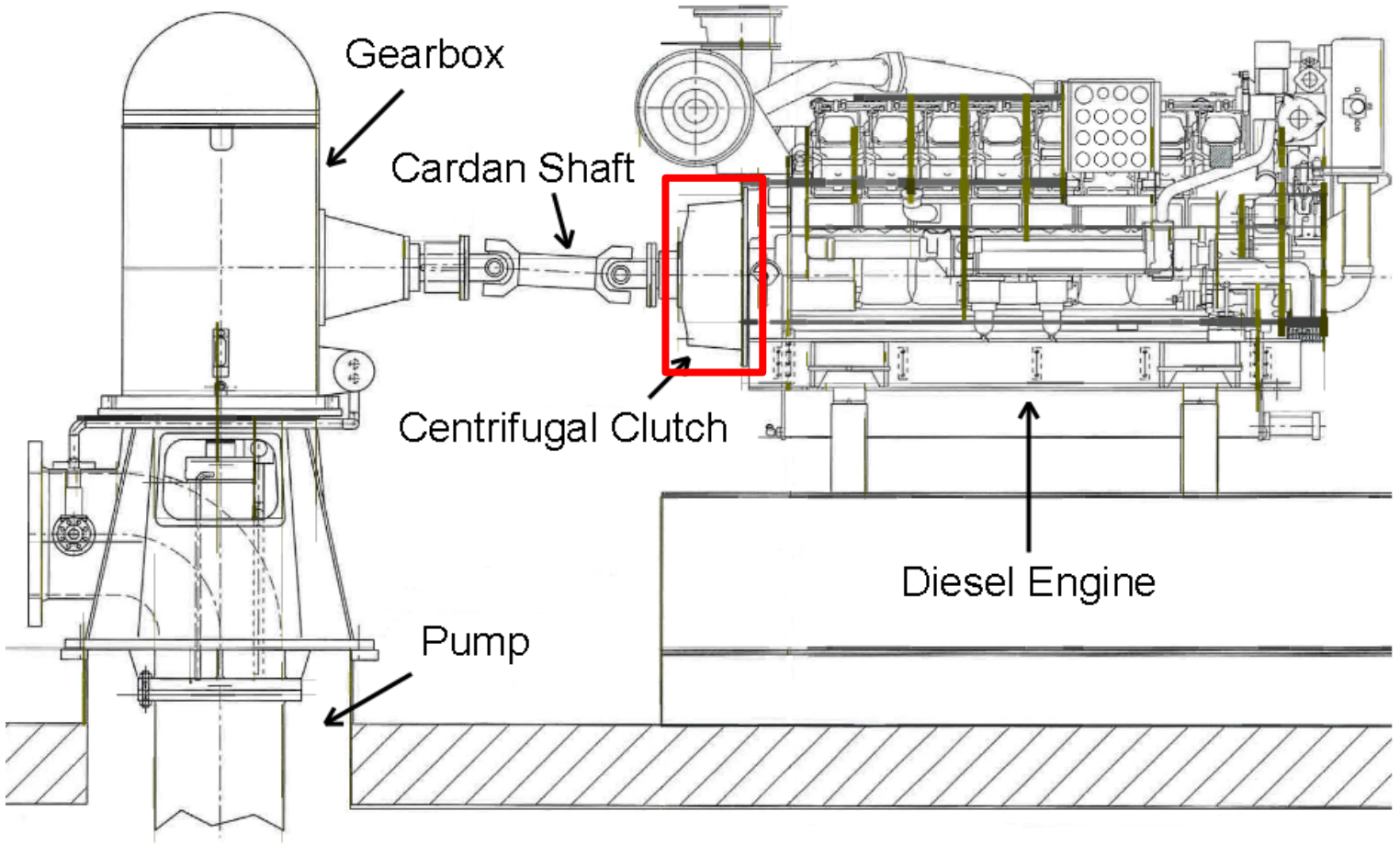
Engine speed: 1800 rpm

Pump speed: 1024 rpm

Engine cylinders: 16

Gearbox ratio: 1:1.7578

Failures occurred on the shaft in the clutch arrangement



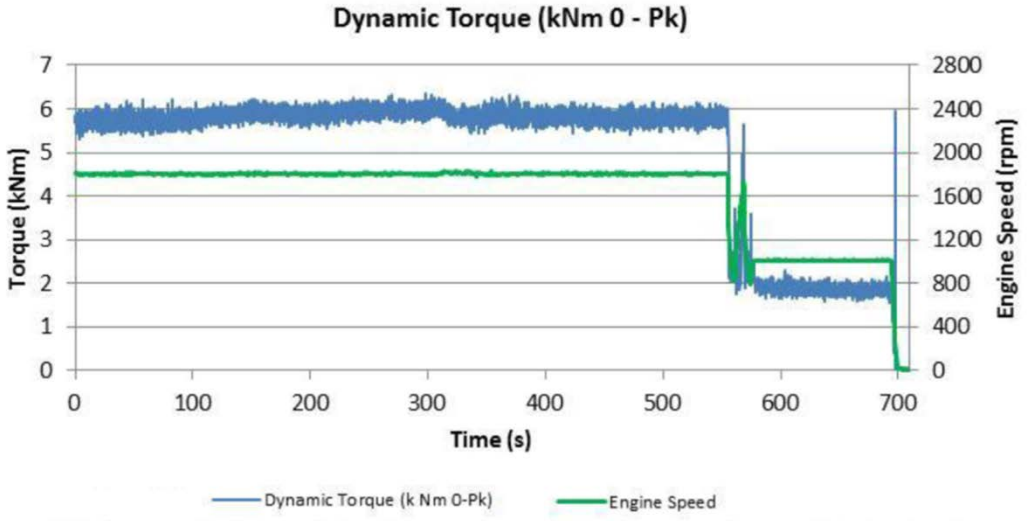
Analysis method and steps taken

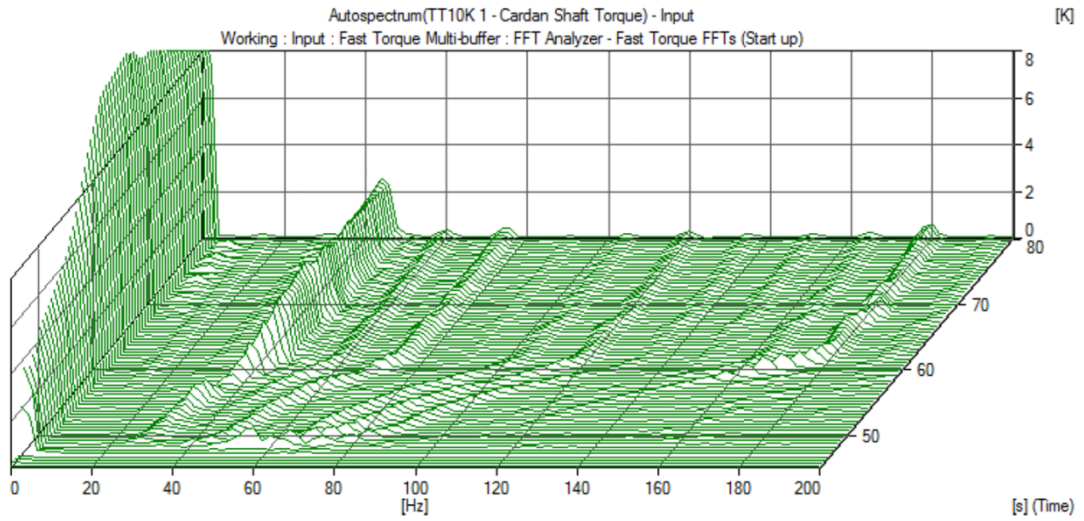
- Dynamic torque was measured on the cardan shaft by another party. The torque was measured in the operating condition at 1800 rpm and during run-up.
- The system torsional natural frequencies were determined from the measurements and compared with the calculated natural frequencies.
- The measured torque response in the cardan shaft as a function of speed was compared to the calculated response.
- The torsional model was updated so that it could reproduce the measured natural frequencies and torque response to an acceptable degree
- The updated model was used to investigate the effect of changing components in the firewater pump string

Torque measurement on cardan shaft

Measurements taken at full speed recorded levels of dynamic torque as high as 6,350 Nm (56,202 lbf-in) 0-Pk.

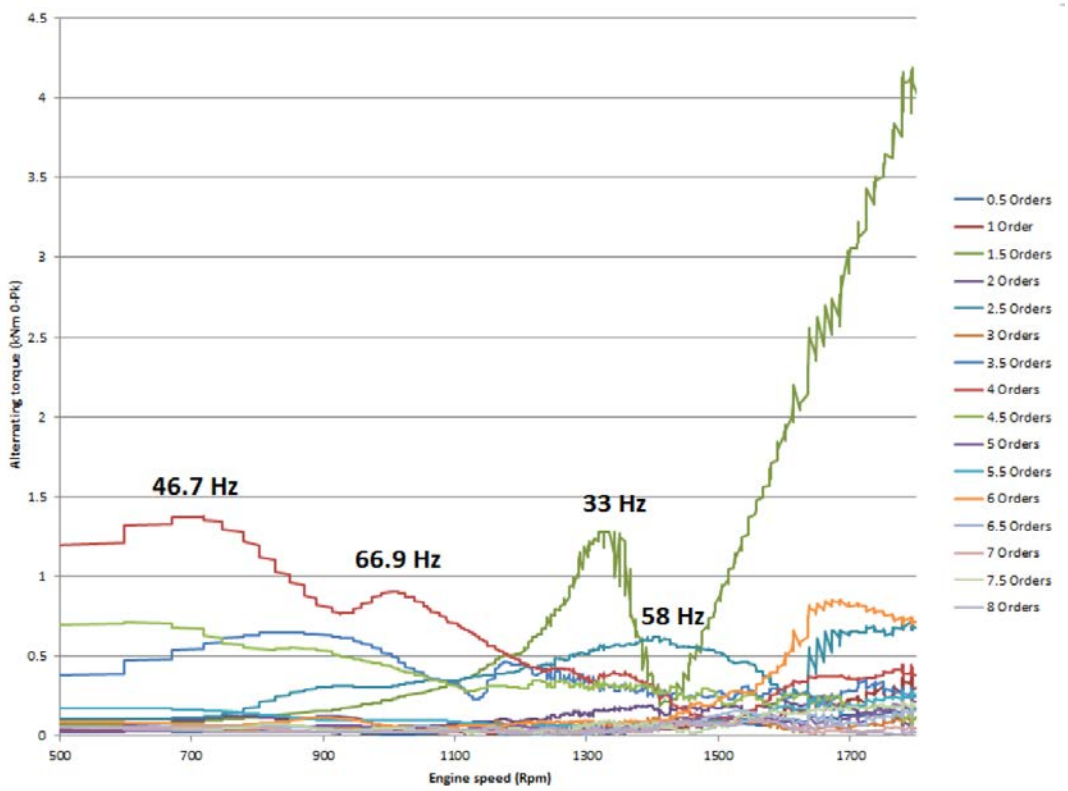
1.5X component dominated the spectrum.





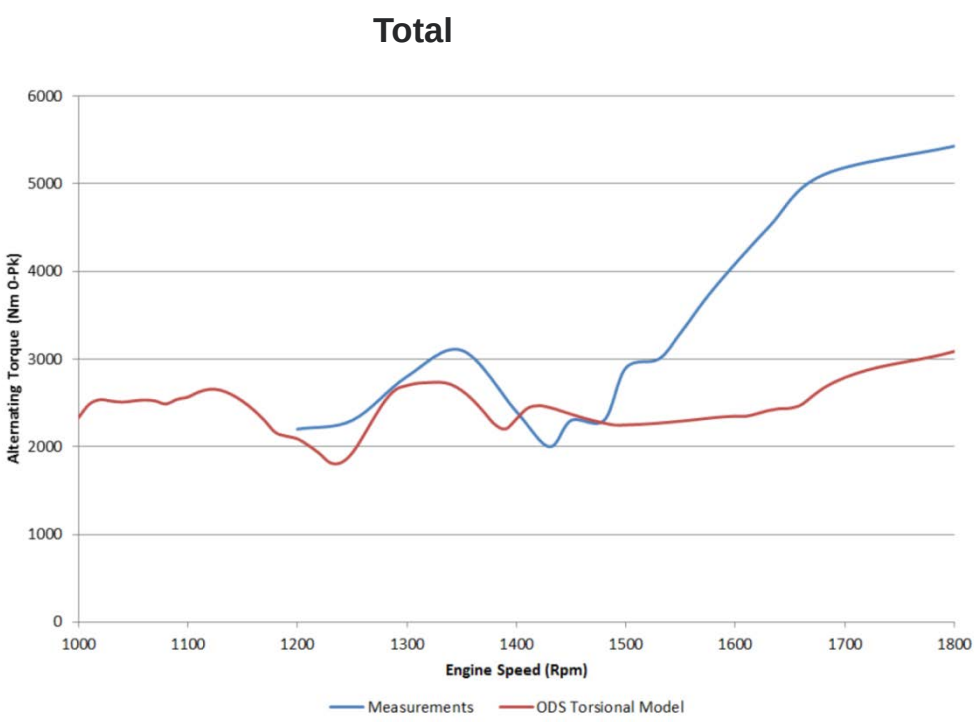
Torque measurement on cardan shaft

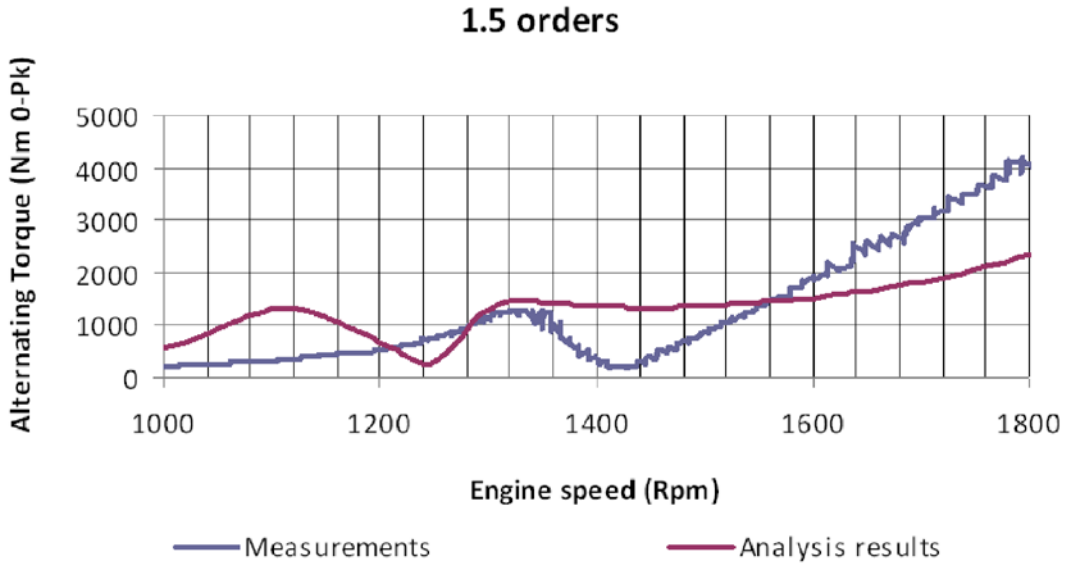
Variable speed test revealed a torsional critical speed around 33 Hz. Furthermore a local minimum was observed around 1430 rpm. The 1.5X was dominating and rising from 1450 rpm and upwards.



Torque measurements vs. torsional analysis

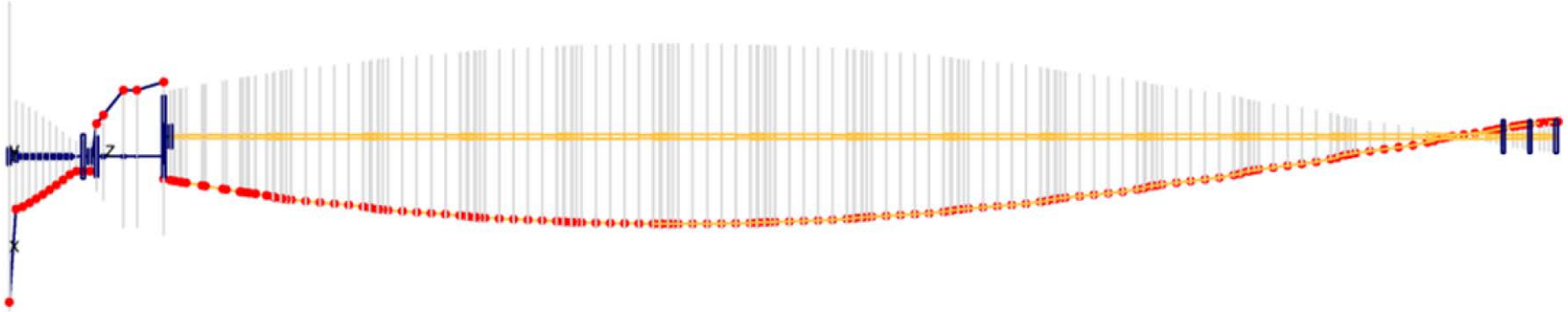
Measured torque 70% higher than predicted by torsional model at operating speed (1800 rpm). Large discrepancies between the measured and calculated dominating 1.5 order component.



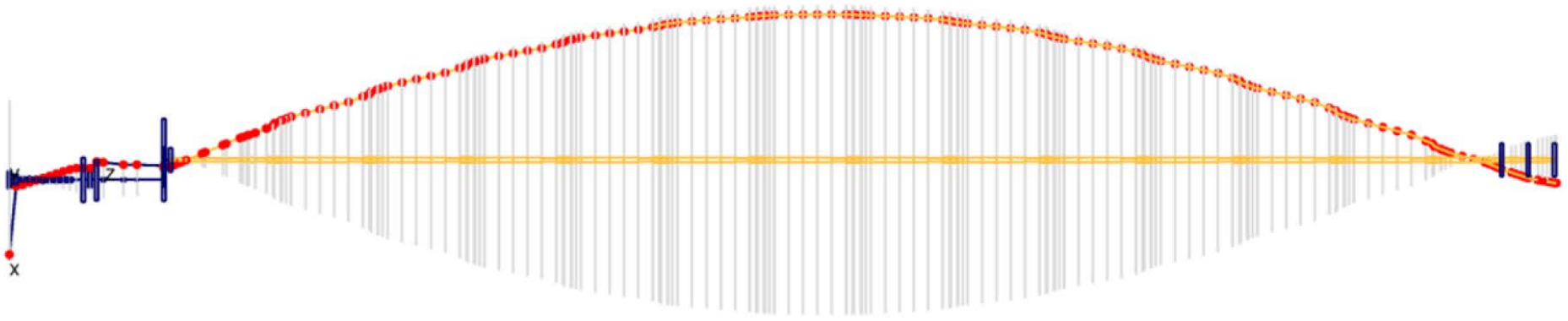


Calculated vs. measured mode shapes

Mode 2: Calculated: 27.4 Hz. Measured: 33.0 Hz.



Mode 3. Calculated: 32.3 Hz. Measured: 46.7 Hz



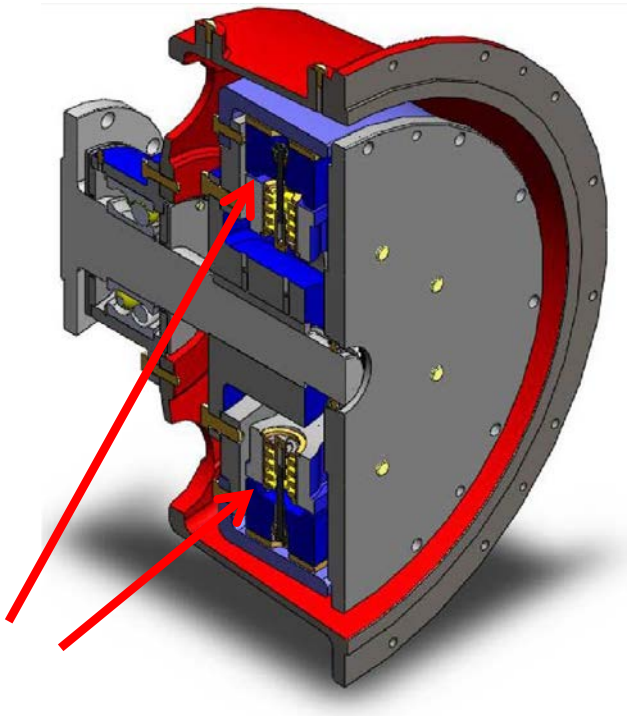
Tuning of torsional model

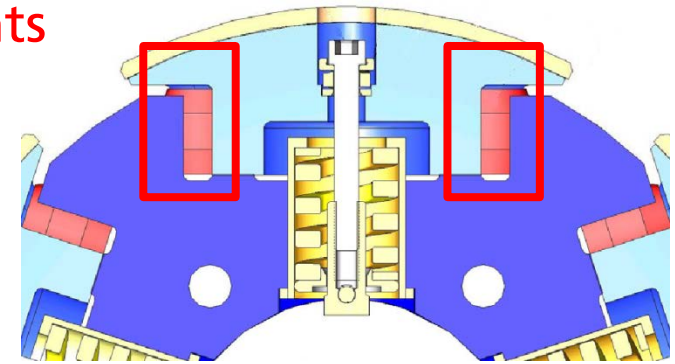
- Dynamic stiffness of centrifugal clutch rubber elements
- Stiffness of pump shaft
- Dynamic stiffness of cardan shaft

Parameter	Nominal value	Updated value
Clutch stiffness	1.06 MNm/rad	4.40 MNm/rad
Cardan shaft stiffness	1.48 MNm/rad	4.40 MNm/rad
Pump elements E-modulus	195 GPa	238 GPa

Dynamic stiffness discrepancy of centrifugal clutch rubber elements

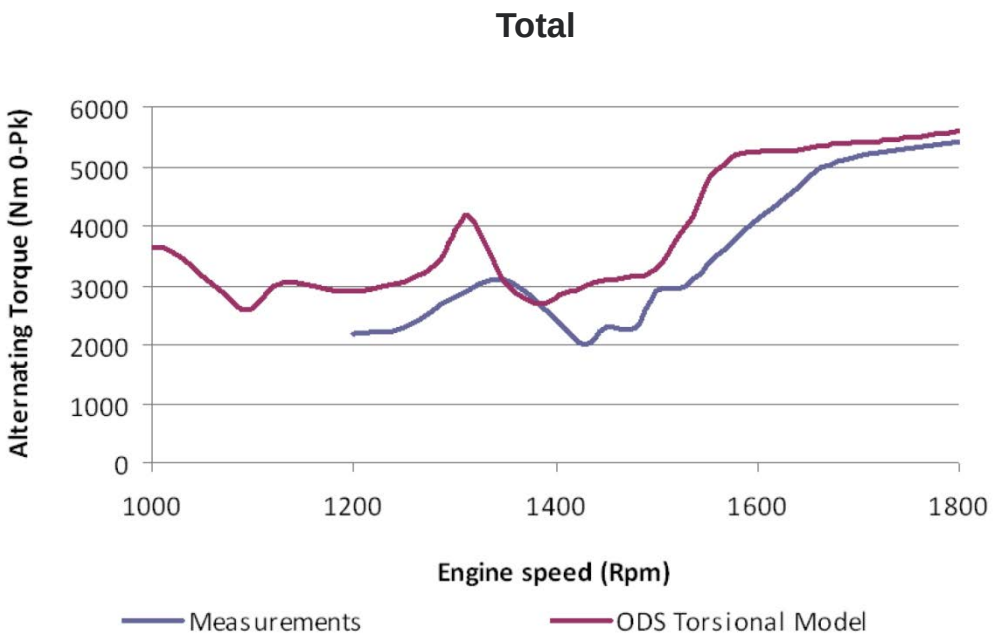
- Apparently, no testing had been made by manufacturer to verify the calculated stiffness of the clutch.
- Manufacturer's dynamic stiffness calculation assumed the excitation frequency of the clutch to be 5 Hz and that the magnitude of the dynamic torque was 20% of the mean torque.
- The main excitation frequency at full speed in this case was 45 Hz and the magnitude of the dynamic torque was measured to be 60% of the mean torque.

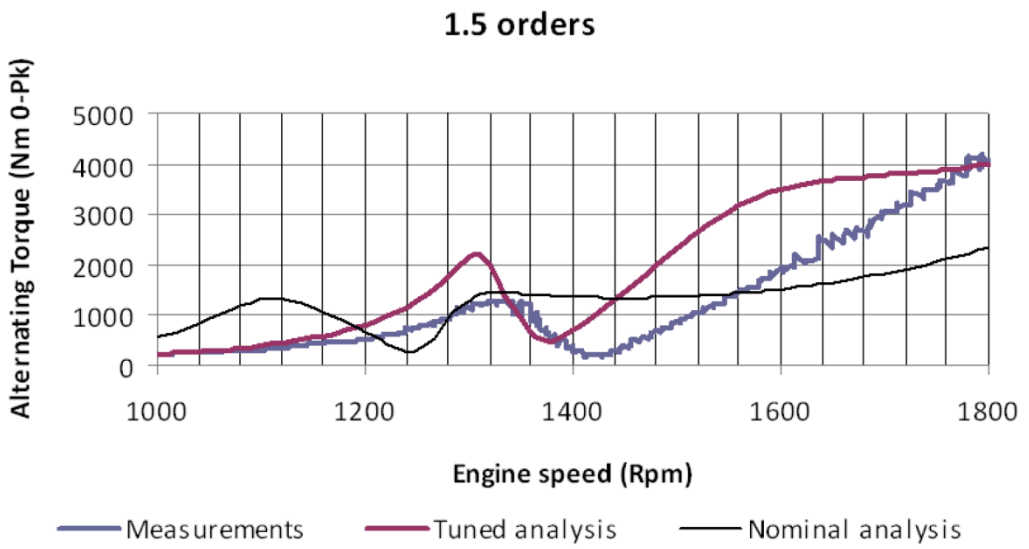




Modeling results – tuned model

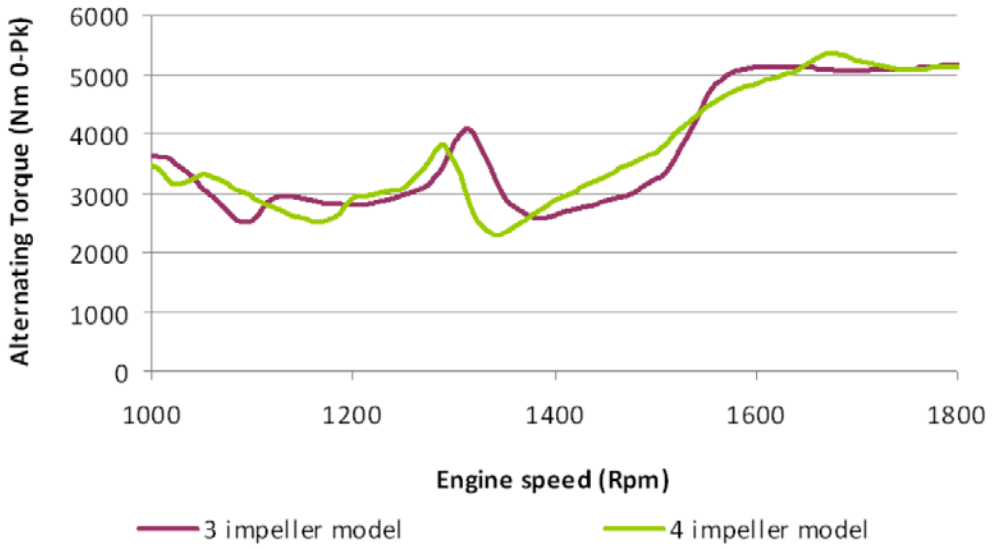
The speed dependence of the 1.5 order component as well as the total torque, in the 1450 – 1800 rpm range, is much closer to the measurements for the updated model.





Short term solution – 4 impeller pump and decreased speed

- It was found that sufficient head could be delivered by installing another pump impeller and decreasing the engine speed to 1441 rpm
- The updated torsional model predicted the torque level at 1441 rpm to be acceptable
- 4 stage pump was built and engine speed re-set to 1441 rpm
- Measurement of dynamic torque confirmed model predictions

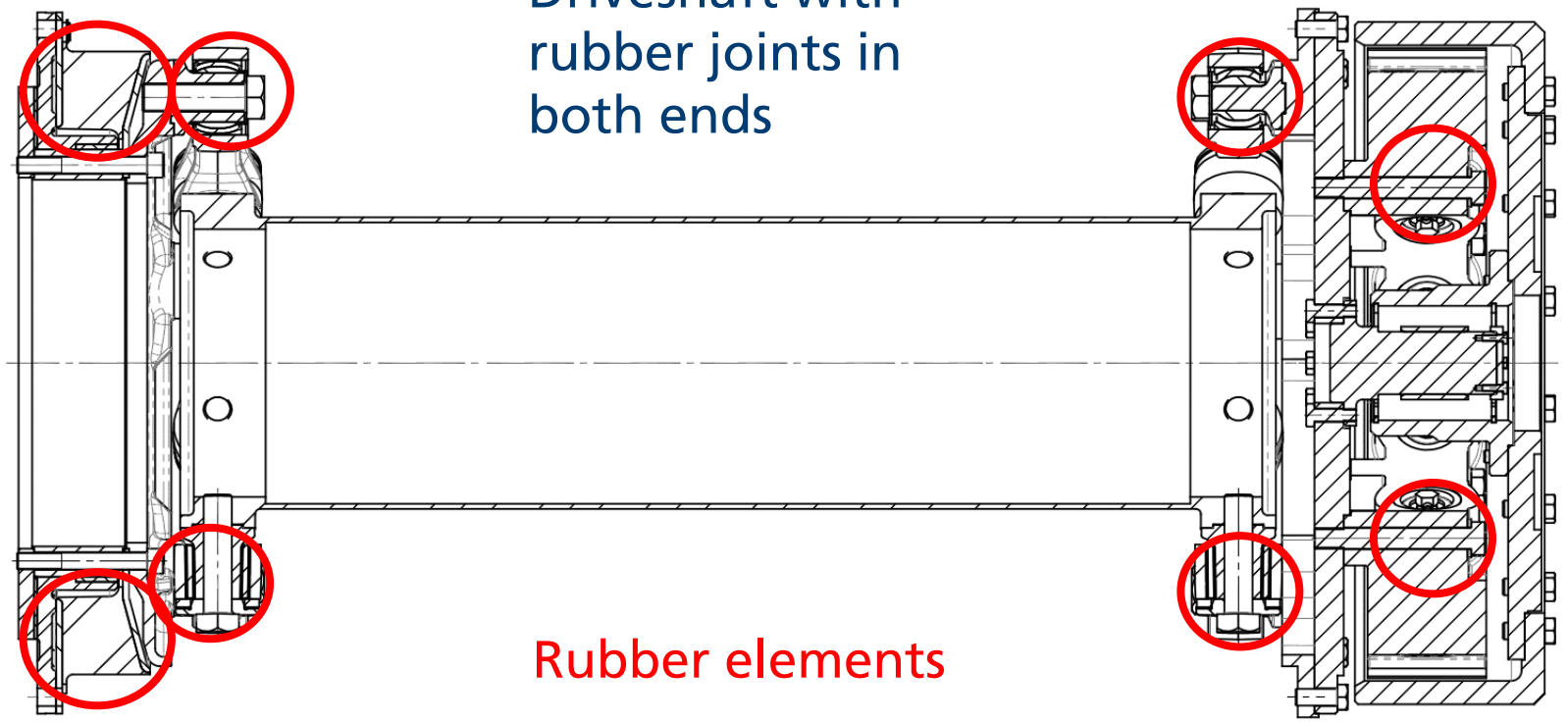


Long term solution – new driveline between engine and gearbox – engine speed 1441 rpm and 4 pump impellers

Torsionally soft coupling attached to engine flywheel – engine running at 1441 rpm

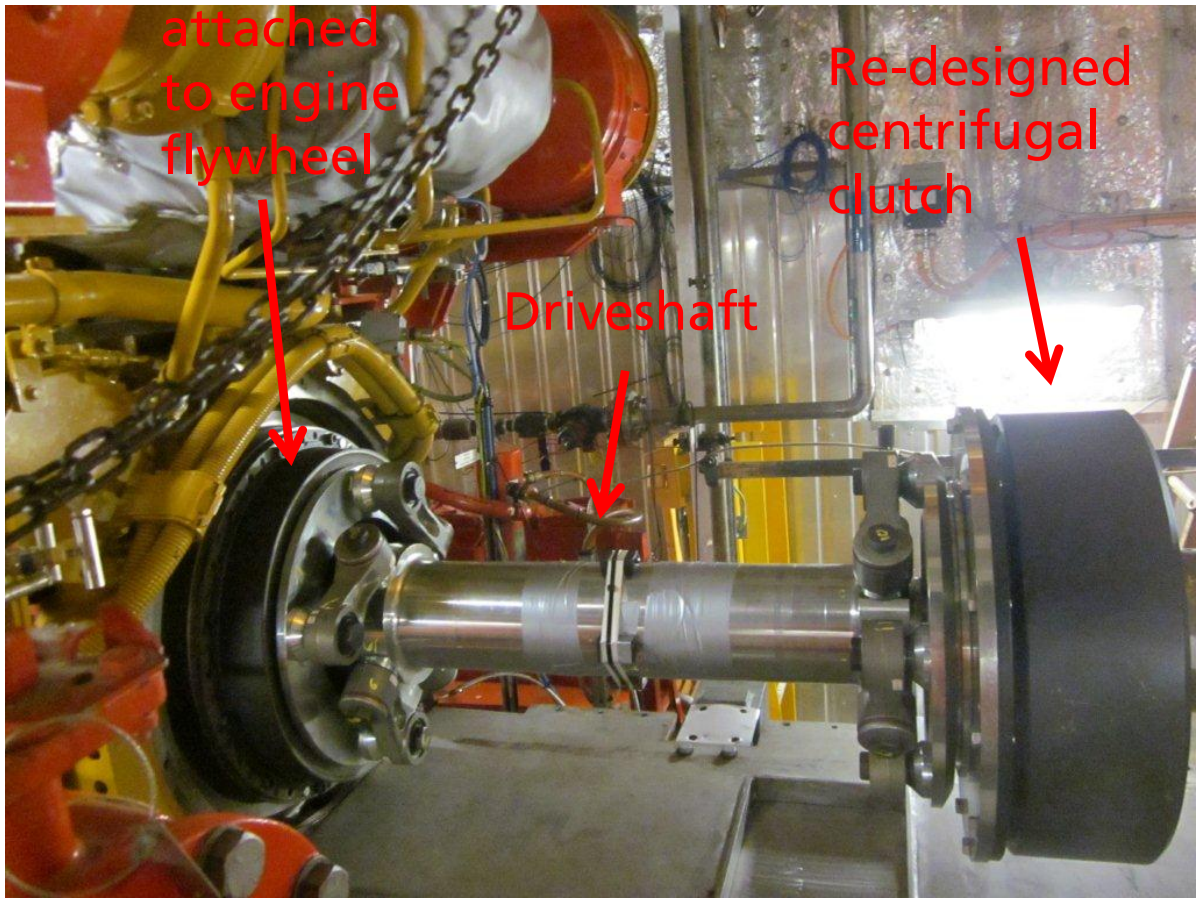
Driveshaft with rubber joints in both ends

Re-designed centrifugal clutch, without stub-shaft, bell housing and thrust bearing, attached to gearbox pinion hub

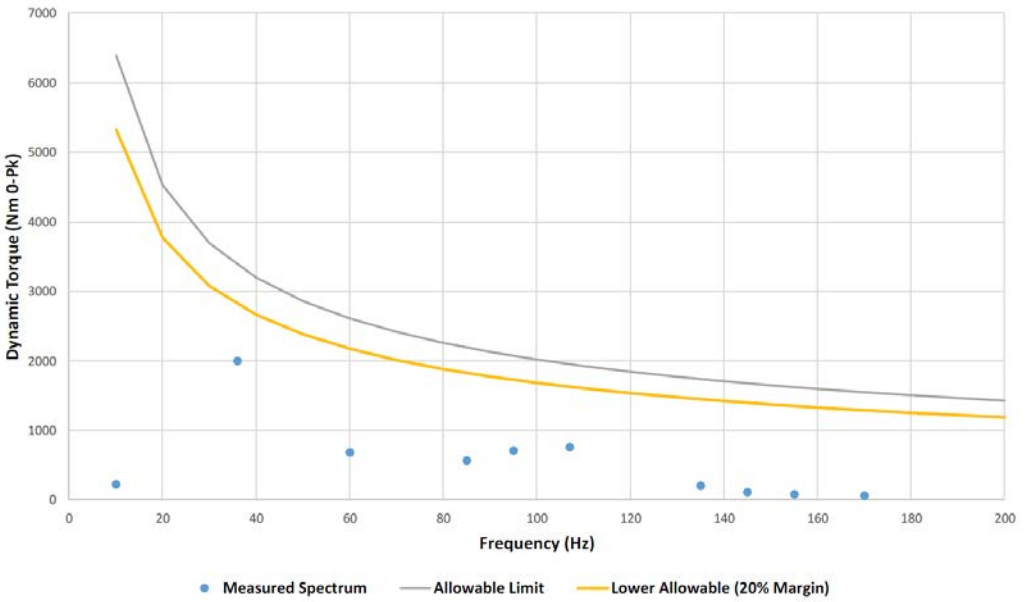


Rubber elements

Photo of new driveline between diesel engine and gearbox



Calculated dynamic torque on driveshaft	Measured dynamic torque on driveshaft
0.88 kNm 0-p	2.54 kNm 0-p



Final results

- Short term solution with 4 impeller pump running at 1441 rpm chosen based on tuned model
- 4 impeller pump installed and modeling results were verified by measurements
- Long term solution with 4 impeller pump running at 1441 rpm and with new driveline between diesel engine and gearbox was selected based on tuned model
- Measurements showed torsional vibration levels to be acceptable on new drivetrain
- Fire water pump trains commissioned in October 2013

Lessons learned

- Important to be critical and use experience and technical knowledge in initial torsional analysis
- Torsional stiffness of rubber elements can vary significantly depending on excitation frequency and the dynamic torque/mean torque ratio, effecting precision of torsional analysis
- A torsional model which is tuned using measurement data is a powerful tool when modifying a drivetrain

Questions?